Energy Insecurity

The False Promise of Liquid Biofuels

T. A. "Ike" Kiefer, Captain, USN

Some prominent arguments appear almost daily in the media that biofuels will increase our domestic supply of transportation fuel, end our dependence on foreign oil, reduce military vulnerabilities on the battlefield, and generally improve national security. Biofuels are further touted to reduce fuel price volatility, polluting emissions, and greenhouse gases (GHG) and even stimulate the economy. These arguments all fall apart under scrutiny. The promise and curse of biofuels is that they are limited by the energy that living organisms harvest from the sun and suffer a fatal "catch-22": uncultivated biofuel yields are far too small, diffuse, and infrequent to displace any meaningful fraction of US primary energy needs, and boosting yields through cultivation consumes more energy than it adds to the biomass. Furthermore, the harvested biomass requires large amounts of additional energy to convert it into the compact, energy-rich, liquid hydrocarbon form required for compatibility with the nation's fuel infrastructure, transportation sector, and especially the military. The energy content of the final-product biofuel compared to the energy required to produce it proves to be a very poor investment, especially compared to other alternatives. In many cases, there is net loss of energy. When energy balance (energy output minus energy input) across the full fuel creation and combustion lifecycle is considered, cultivated liquid biofuels are revealed to be a modern-day attempt at perpetual motion that is doomed by the laws of thermodynamics and a fatal dependence on fossil fuel energy. The United States

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cannot achieve energy security through biofuels, and even the attempt is ironically achieving effects contrary to "clean" and "green" environmental goals and actively threatening global security.

This article focuses on cultivated biomass converted into liquid transportation fuel, and all references to *biofuels* throughout refer to these circumstances unless specified otherwise. The overall approach is an analysis of alternatives comparing three distinct biofuels methodologies with conventional petroleum fuel to assess their relative costs and benefits. It begins by considering what energy security means in terms of fuel quality and supply, then builds an analytical framework of key parameters and evaluates how each of the biofuel methodologies fall short. Next it provides evidence that pursuit of biofuels creates irreversible harm to the environment, increases greenhouse gas emissions, undermines food security, and promotes abuse of human rights. The article concludes with specific recommendations for policy and action.

Energy Security

The ability of biofuels to truly substitute for petroleum fuels is the core question addressed here. The US Congress has authoritatively defined *energy security* in Title 10 of the US Code as "having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements."[1] In 2011, the United States imported 45 percent of its petroleum, and this generates concern because of US dependence on other nations for supply and unpredictable global market price volatility.[2] If a way existed to reliably supply US transportation energy exclusively from domestic sources with reasonable and stable prices, it would clearly enhance energy security.

An Appeal to Science over Politics

This research is based on an extensive literature survey of recent and reputable sources emphasizing US government agency data published in official reports and university studies published in peer-reviewed scientific journals. Since 2008, a new generation of more rigorous studies has dramatically undermined the naïve assumption that biofuels are inherently clean and green, carbon-neutral, and the world's solution to petroleum dependence. But these watershed scientific documents have so far had little impact on US government or military energy policy. The US Navy

directly rejected a RAND study conducted at the direction of Congress and delivered to the secretary of defense in January of 2011 that unambiguously found biofuels of "no benefit to the military."[3] A second RAND study and a report by the US National Academy of Sciences, both severely questioning the wisdom and efficacy of current US biofuels policies, also resulted in no adjustments to US biofuels programs.[4] In August 2012, the German National Academy of Sciences, in a country very aggressive in its pursuit of alternative energy, released the report of a three-year study that concluded biofuels offer little or no benefit in reducing GHG emissions and that "the larger scale use of biomass as an energy source is not a real option for countries like Germany." The German scientists even went so far as to flatly recommend all of Europe abandon biofuel production mandates.[5] In October 2012, the National Research Council released a report which critically questioned the feasibility of sustainable production of algae-based biofuels and highlighted five areas of major concern that parallel and support arguments made in this article against all cultivated biofuels.[6] These are but a few of the studies that point out fatal flaws in pursuing biofuels as a substitute for petroleum. There are several key parameters that, when understood, help to evaluate the utility of fuels and the costs and consequences of their production and use.

The Science of Fuels

The energy carriers in fossil fuels and biofuels are hydrogen and carbon atoms. Hydrogen is abundant, is very reactive in accepting and releasing energy in its chemical bonds with other atoms, and is the lightest element, giving it a very high *gravimetric energy density* (joules per kilogram). Pure hydrogen powers everything from microorganisms to turbine engines.[7] Carbon is another common and lightweight element with very high combustion energy. It also readily forms long molecular chains and can serve as a backbone to organize many other atoms into dense and neatly organized packages. Combined with hydrogen in equal parts, it forms highly versatile and energetic liquid fuels. Carbon transforms hydrogen from a diffuse and explosive gas that will only become liquid at -423° F into an easily handled, room-temperature liquid with 63 percent more hydrogen atoms per gallon than pure liquid hydrogen, 3.5 times the *volumetric energy density* (joules per gallon), and the ideal characteristics

of a combustion fuel.[8] If we did not have carbon, we would have to invent it as the ideal tool for handling hydrogen.

In 1909, Fritz Haber discovered the chemistry of converting natural gas into ammonia (i.e., converting fossil fuel into plant fuel). Ammonia (NH_3) is a potent organic fuel for most bacteria and plants which have the ability to metabolize its nitrogen and hydrogen energy.[9] Placing ammonia in the soil to fuel plant growth is known as "nitrogen fixing."[10] It can be done naturally and slowly by symbiotic soil and root bacteria using photosynthesis energy borrowed from their host plant, or it can be done artificially and quickly by humans manufacturing it and plowing it into the soil.[11] The manufacture of ammonia is second only to plastics in consumption of US industrial energy, and 80 percent of ammonia goes into making fertilizer.[12] Today, Iowa farmers pump pure liquid ammonia into the soil at the rate of 150–200 lbs/acre[13] to harvest consecutive annual crops of 160–180 bushels per acre of corn—a sixfold increase over historical yields.[14] It is largely because of the global conversion of fossil fuel energy into food that the world has avoided Robert Malthus' 1798 prophecy of global famine from population growth overtaking food production.[15]

Without the addition of artificial fertilizer energy, plants are limited to getting their energy from the sun. The devastating limiting factor for all biofuels is that photosynthesis captures solar energy with surprisingly poor speed and efficiency—only about 0.1 percent of sunlight is translated into biomass by the typical terrestrial plant,[16] and this translates into an anemic *power density* of only 0.3 watts per square meter (W/m^2).[17] This is 20 times worse than the 6.0 W/m^2 that current solar panels arrayed in large farms can collect from the same sunlight and acreage.[18] Humans must input fossil fuel energy in the form of ammonia fertilizers to overcome this solar limit on biomass production for crops. While this is a justifiable option to increase food production, it makes no sense to add energy to something that is supposed to be an energy source such as biofuel crops. It is also nonsensical to add fossil fuel energy when the objective is to *displace* fossil fuel energy.

A perfect combustion fuel possesses the desirable characteristics of easy storage and transport, inertness and low toxicity for safe handling, measured and adjustable volatility for easy mixing with air, stability across a broad range of environmental temperatures and pressures, and high energy density. Because of sweeping advantages across all these parameters, liquid hydrocarbons have risen to dominate the global economy. No materials

other than very exotic and toxic substances like lithium borohydride ($LiBH_4$) or expensive rare metals like beryllium surpass the energy density of diesel and jet fuel. Biodiesel and ethanol both fall short. Hydrogen fuel cells, electrical storage batteries, and capacitors miss by a much greater margin. Other alternatives, such as wind, solar, geo-thermal, or waste-to-energy devices, can power some laptops and light some fixed facilities but simply cannot harvest enough energy to propel the tanks, jets, helos, and trucks that are by far the major battlefield fuel consumers. These can offer only an incidental decrease in overall fuel requirements for mechanized forces and then only in low-hostility circumstances where they can be set up and safeguarded.

In addition to inorganic and organic chemistry, an energy strategist must understand two unbreakable laws of the universe. The first law of thermodynamics (conservation) states that energy is neither created nor destroyed, but only changes form. The second law (entropy) distinguishes between useful energy that can perform work and useless energy that cannot. It holds that some fraction of useful energy irreversibly becomes useless every time energy is converted from one form to another. In other words, any conversion process consumes some of the useful energy and leaves less in the output products. Together, these two laws declare that the amount of useful energy that can be recovered from a system is always less than the energy that was put into the system. Every transaction, process, or conversion pays an energy tax, which is why it is impossible to construct a perpetual motion machine. The ratio of energy-out to energy-in is a critical parameter in evaluating energy sources.

Energy Return on Investment

For energy strategists to get the right answers, they must first ask the right questions. When choosing a primary energy source and a fuel to derive from it, it is essential to be sure the fuel will meet the demands of the civilization that will consume it—not only in terms of quantity, but even more fundamentally, in terms of quality. One key measure of fuel quality is how much useful energy the fuel yields divided by how much energy is required to extract the primary energy source from the environment and convert it into that fuel. This metric is known as *energy return on investment* (EROI).[19]

$$\text{EROI} = \frac{\text{Energy available in newly produced fuel}}{\text{Energy consumed in producing the new fuel}}$$

Raw primary energy sources require some energy to be consumed to process them into finished fuels. An EROI of 1:1 would mean the useful energy in a newly produced quantity of fuel is exactly equal to the energy consumed in its production. It might seem that any EROI greater than unity is of net benefit to civilization, but this is not the case. A modern civilization requires a much greater return on its investment, because survival and standard of living depend upon the size of this margin.

Civilization Is a Living Organism

Dynamic energy budget (DEB) theory is a sophisticated approach to looking at living things in terms of energy.[20] A thermodynamic analysis reveals that any organism can only afford to expend a small fraction of its current energy stores finding and processing new primary energy sources into fuel (*assimilation*) because there are many other essential energy-consuming (*dissipation*) tasks it must perform to survive; these include sustainment, repair, protection, maturing and increasing in complexity, and reproduction. Only if there is surplus energy after all of these demands are fully satisfied will the organism increase its mass (*growth*). To power all these activities, the organism needs food that is not just fractionally positive in net energy, but rather has an EROI many multiples greater than unity. A civilization is itself a high-order physical and biological organism that has tremendous overhead costs and can spare only a fraction of its energy to assimilate new energy.

Minimum EROI for Modern Civilization

A study of historical US economic performance over the last century has found that economic recessions are linked to primary energy EROIs dipping below a critical threshold of 6:1.[21] This value represents the minimum energy quality an industrial civilization must have to sustain a modern, energy-intensive quality of life. Another macroanalysis found that an EROI of 3:1 is the bare minimum quality a raw energy feedstock must have to overcome all the production costs and conversion losses and still deliver positive net energy to modern civilization.[22] A 3:1 EROI thus also represents a critical tipping point. To put these values in biological terms, a modern industrial civilization is very energy-hungry, and if undernourished on a diet of foods with lean EROIs below 6:1, it becomes catabolic, eating into the fat of its savings and the muscle tissue of its infrastructure to replace the missing calories. As long as EROI

remains below 6:1, industrial civilization is locked into a death spiral where an ever increasing fraction of its economic output (GDP) is spent on energy at the cost of eroding standard of living.[23] At EROIs below 3:1, the food is so poor that digesting it into fuel takes more energy than it returns, and full starvation sets in. The only way out of this hunger trap is either to find higher-EROI energy or to decay into a preindustrial civilization with lower energy needs.

The bottom line is that a healthy modern economy must be fed by hearty primary energy sources with a collective EROI above 6:1. Purposely displacing high-EROI energy sources with anything that returns less than 6:1 is ill advised. Plotting out fuel EROI estimates versus their current energy contribution to the US economy provides a useful perspective on their relative utility (fig. 1). [24]

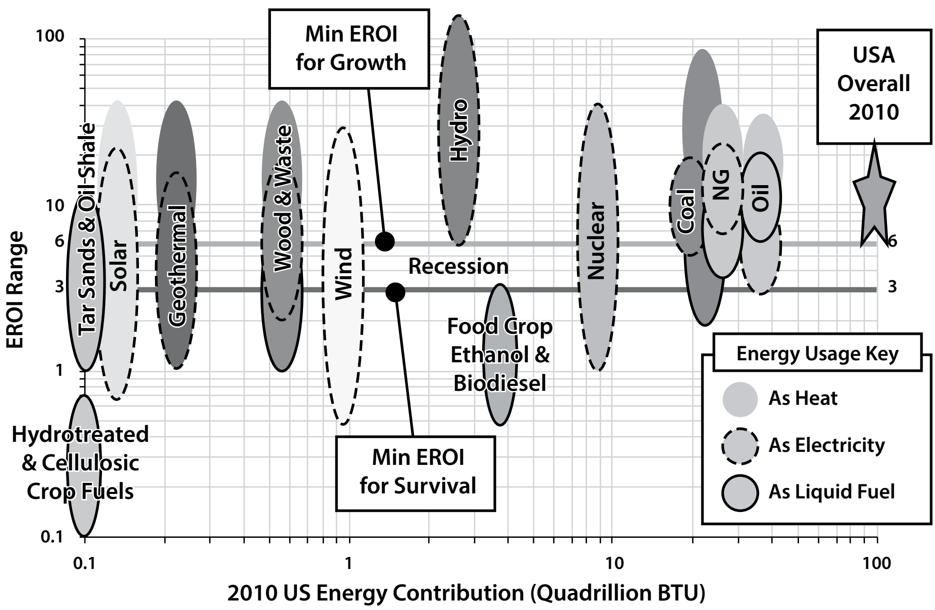


Figure 1. Energy return on investment (EROI) of US energy sources

Evaluating Biofuels

Food Crop Ethanol

Over the past 70 years, the United States has nearly perfected corn as a high-yield food and industrial starch feedstock. Unfortunately, the laws of physics exact large energy tolls from processes that require many

conversions, such as producing liquid fuels from solid biomass. After decades of study and experimentation and continuously refined commercial production, the scientific literature consensus for corn ethanol EROI is a lowly value of 1.25:1.[25] Even worse, there is no net gain in liquid fuel energy—the ethanol produced contains energy barely equal to the input fossil fuel energy. The small energy profit is contained in byproducts, principally high-protein biorefinery leftovers called distillers' dry grains and solubles (DDGS) that can be used as cattle feed. More than $6 billion a year in direct federal assistance to corn growers and ethanol refiners since 2005 has served only to reduce a nonexistent foreign dependence on animal feed protein supplements.

It should be pointed out that the corn ethanol EROIs published in the literature and discussed above are not for a pure corn ethanol lifecycle, but for a hybrid lifecycle involving both fossil fuel and corn ethanol where fossil fuel provides much of the input energy. A proper corn ethanol EROI would be calculated using corn ethanol as the exclusive energy source to make more corn ethanol, but no example is available today. This is telling. It will be shown below by lifecycle analysis that making corn ethanol is a negative energy-balance process that consumes more than five-sixths of the energy invested. Civilization would get six times more output energy from the fossil fuel diverted to make corn ethanol if it were instead used directly as fuel.[26]

Modern intensively farmed corn, with its huge appetite for fossil fuel–based ammonia and agrichemicals, is making a large, net negative contribution to the nation's energy budget and working to increase rather than decrease petroleum demand. Using biomass to replace fossil fuels is futile if a large portion of the energy invested to make them is *from* fossil fuel. Applying ammonia fertilizer to any crop intended for biofuel is an indefensible waste of energy.

Cellulosic Ethanol

The facts are even less kind to liquid fuels made from cellulosic materials such as wood, switchgrass, and harvest wastes, which contain no easy sugars and starches. Cellulose can be broken down into fermentable sugars but must first be separated from the lignin. Paper manufacturers use concentrated acid and explosive steam treating known as the "Kraft process." However this one step alone consumes as much energy as exists in the final ethanol. Those who want to make energy out of lignocellulose

must use much slower and more expensive enzyme or microbial processes; and then still remains fermentation, distillation, and dehydration. A rigorous thermodynamic analysis found that cellulosic ethanol is three or more times more difficult to produce than food crop ethanol, with an EROI far below 1:1.[27] However, a much-touted USDA study that assumed away many of the known difficulties and costs to predict a fanciful EROI for switchgrass of 5.4:1 (four times better than corn ethanol) has been used to justify spending billions of dollars in federal and private funds on some high-profile entrepreneurial misadventures.[28] Nevertheless, the proof is in the performance.

Despite all the subsidies, tax breaks, and fuel-mixing mandates since 2005, there is not a single commercially viable cellulosic ethanol facility in the United States today.[29] Rather, the landscape has been rocked by high-profile frauds and failures, such as Cello and Range Fuels.[30] Instead of the 500 million gallons of cellulosic ethanol a year by 2012 promised by huge federal expenditures on startups and biorefineries,[31] the Environmental Protection Agency (EPA) officially counts only one 20,000-gallon commercial transaction to date to an undisclosed buyer.[32] Nevertheless, the EPA continues to fine US oil refineries for not mixing nonexistent cellulosic ethanol into their gasoline.[33] Some of the companies that have been working on cellulosic ethanol the longest—such as Gevo, Amyris, and Cellana—have shifted to corn ethanol, industrial chemicals, and fish food.[34] British Petroleum and others have suspended construction of huge biorefineries in the United States.[35] Other companies such as Coskata and Primus Green Energy are quietly leading a mass migration away from any pretense of renewable fuels to instead boldly embrace synthetic liquid fuels made from natural gas.[36] The former CEO of Codexis, who presided over the spending of $400 million in pursuit of cellulosic ethanol, has publically confessed that making hydrocarbons from carbohydrates is a dead end. He is now at Calysta working on natural gas–to–liquid fuel.[37]

Biodiesel

Plant species which yield some biomass as lipids include soy, camelina, rapeseed, oil palm, jatropha, peanut, sunflower, cottonseed, safflower, and microalgae. All of these crops, including a nonpoisonous Mexican variant of jatropha, have provided human and animal food over the centuries. The natural lipids in these plants can be broken down

by adding methanol to become fatty-acid methyl esters (FAME), commonly known as *biodiesel*. Contrary to popular belief, biodiesel is a very different chemical cocktail than conventional diesel fuel and has a lower energy density and inferior physical properties. To overcome biodiesel and other liquid biofuel shortcomings and make them more compatible with existing fuel infrastructure and high-performance engines, they must be transformed into true "drop-in" hydrocarbons by a series of processes, known as "hydrotreating," that increase the ratio of hydrogen to carbon, remove all oxygen, and change the structure and blend of the constituent molecules.[38] Hydrotreatment greatly increases the cost and reduces the renewable nature of the fuel, because the hydrogen added comes from fossil-fuel natural gas and the process releases 11 tons of CO_2 for every ton of hydrogen added. A national security energy strategist must understand such technical details as these and also be aware that all military aircraft and combat vehicles and civilian airline fleets must have hydrotreated biofuel. Even before being punished by hydrotreatment, biodiesel EROIs calculated from rigorous, full commercial-scale lifecycle studies range from 1.9:1 for soy[39] down to well below 1:1 for microalgae.[40]

Algae is the only biodiesel crop with high-enough potential yields to replace petroleum without consuming all US territory and deserves further consideration. Optimistic studies have projected algae biodiesel to achieve much higher EROIs, but a critical analysis of their assumptions reveals they depend on a host of unrealistic circumstances. These include massive supplies of free water and nutrients, a free pass on enormous environmental impact, and market economics that miraculously transform enormous accumulations of soggy biomass byproduct with a per-ton value less than the cost of transportation into a cash commodity crop. A literature survey of reported algae EROIs performed by the National Research Council found values from 0.13:1 to 7:1, but in the higher cases, energy credits from co-products dwarfed the energy delivered as liquid fuel—biodiesel was really the co-product and solid biomass the product.[41] Algae are much more efficient in producing "soylent green" than in producing green fuel. Proponents often claim that algae need only sunlight and CO_2 to grow. In practice, however, the need for high yields compels use of fossil fuel–based commodity fertilizer typically delivered as urea.[42] Solazyme Inc., the US Navy's choice for algae biofuel, actually grows its product in dark bioreactors using carbon and hydrogen energy in the form of sugar. This makes it unique in producing a biofuel 100 percent dependent upon a

food crop and getting 0 percent of its energy from the sun via direct photosynthesis—a worst-case scenario.[43]

The simple but decisive math is that, even at commercial scale with generous assumptions about cellular reproduction rate and lipid fraction and oil extraction, and ignoring the costs of facilities and water, Argonne National Laboratory has calculated that it takes 12 times as much total energy and 2.6 times as much fossil fuel energy to put a gallon of algae biodiesel in a gas station pump instead of a gallon of petroleum diesel—and this is before hydrotreatment.[44] Direct comparison of alternatives is a sound evaluation technique and introduces the important economic concept of *opportunity cost*.

Fuel Lifecycles and Opportunity Cost

Not only should new fuels have an EROI greater than 6:1, they should also have an EROI greater than available alternative fuels suitable to the same purpose. If they have a lower EROI and their use is compelled, production will sap energy from higher EROI fuels and create an energy deficit to the economic sector they serve.[45] This can be demonstrated by comparing petroleum fuels to corn ethanol. Current petroleum diesel and gasoline production EROIs are variously estimated between 10:1 and 20:1. A conservative approach least favorable to petroleum is to postulate an 8:1 EROI, which represents the lowest value calculated since 1920.[46] An 8:1 EROI means that one barrel of liquid fuel energy input can support the exploration, drilling, extraction, and refining of enough crude oil to make eight new barrels of liquid fuel energy[47]—which for petroleum happens to come with a bonus of one barrel of chemical feedstock for plastics, lubricants, organic compounds, industrial chemicals, and asphalt (see fig. 2).[48] The much lower 1.25:1 EROI of corn ethanol means that to produce the same net gain of eight barrels of energy requires *not one, but 32 barrels* of input energy. And for ethanol, the output energy profit is delivered not as liquid fuel, but as 5.5 tons of cattle feed co-product. The 52 barrels of lower energy density, lower compatibility, and more corrosive ethanol produced as the primary product contain just enough energy to make up for the 32 barrels of fossil fuel energy used to make them and deliver no net energy gain. This picture looks completely different than the one in biofuels advocacy literature because it shows true lifecycle and opportunity costs, not just a misleading combustion-only comparison of a barrel of oil versus a barrel of ethanol.

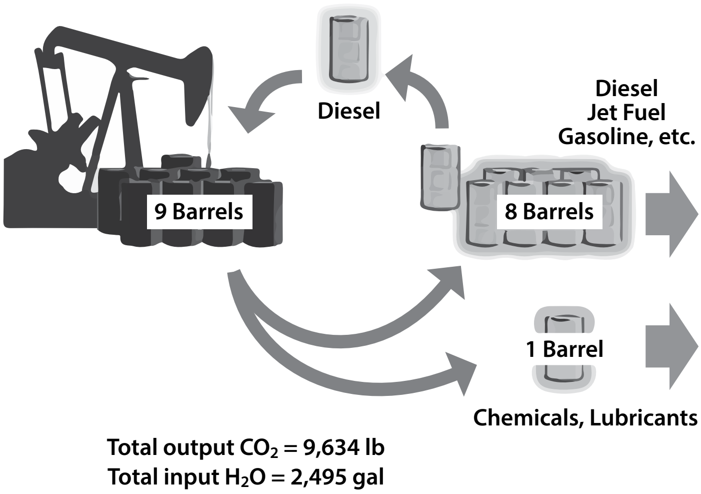
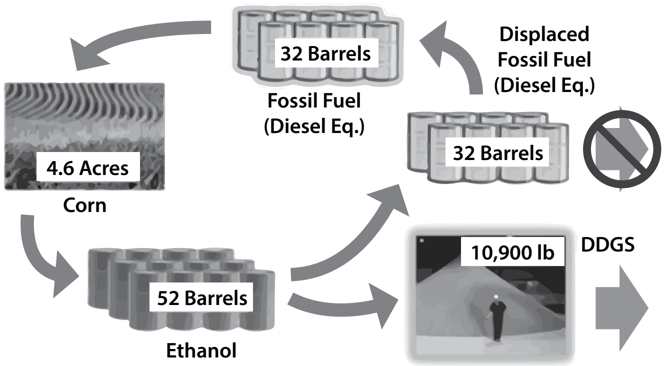


Figure 2. Petroleum motor fuel lifecycle at 8.0:1 EROI

Biofuels can only truly substitute for petroleum fuels when the EROIs of both converge, and this cannot happen if the former is an energy parasite of the latter. The parasitic dependence of biofuels upon fossil fuels precludes any chance of their reducing dependence on foreign oil, assuring domestic supply, or stabilizing prices. Liquid biofuel prices are already as volatile as oil prices and track up and down with the international oil market.[49] Deriving fuel from farming further increases price volatility by adding an additional linkage to global agricultural commodities markets. Energy security is reduced by choosing a fuel subject to floods, freezes, and droughts, and which must be recreated annually from scratch with no proven reserves.

To summarize the corn ethanol fuel lifecycle depicted in figure 3, it is the transformation of 4.7 tons (180 gigajoules) of high-quality fossil fuel and 11,000 tons of fresh water into 7.2 tons of lower-quality ethanol fuel-additive (180 gigajoules) and 18.5 tons of CO_2-equivalent, all for the net creation of 5.5 tons of protein supplement.[50] From the perspective of opportunity cost, one barrel of fossil fuel energy can either deliver 340 pounds of DDGS or 2,200 pounds (336 gallons, 1 metric ton) of petroleum fuel. The much more efficient and economical path to generate high-protein animal feed supplement chosen by US farmers in the absence of ethanol subsidies is growing soy, which fixes its own nitrogen and has 49 percent protein content vice 27 percent for DDGS.[51] Compared to the petroleum fuel lifecycle (fig. 2), the corn ethanol fuel lifecycle (fig. 3) consumes 3.5 times more fossil fuel, more than triples GHG



Total output CO_{2e} = 37,120 lb (3-fold increase)
Total input H_2O = 2.7M gal (1,000-fold increase)

Figure 3. Corn ethanol motor fuel lifecycle at 1.25:1 EROI

emissions, increases water use by three orders of magnitude, adds environmental costs from agrichemical runoff while still suffering those associated with crude oil, and competes with food cultivation for cropland acreage and associated agricultural production capital and resources.

Closer examination reveals how intractable is biofuels' dependence on fossil fuel energy. Fossil fuels provide 82 percent of all US energy, including the vast majority of electric power and 94 percent of liquid transportation fuel.[52] They provide the farm machinery fuel and processing plant heat and electricity used to make biofuels from biomass. Petroleum and natural gas are also the feedstock for the massive organic chemical industry that makes the herbicides and pesticides applied to biofuel crops and the designer enzymes used in the latest high-technology approaches. The energy to prepare the giant yeast and microbe cultures that ferment the sugars into alcohol and the immense heat needed to distill the 4 percent alcohol beer into 99.5 percent pure anhydrous ethanol are overwhelmingly supplied by fossil fuel. Of course the energy used to build the biorefineries in the first place and to transport the final product to market is largely from fossil fuel as well. Some might argue that all of the above is only true because biofuels have not yet gained enough of a market share to provide these energies. However, the truth is that biofuels have been around for a century (the first US commercial cellulosic ethanol plant was opened in 1910)[53] but have failed to gain market share because they are a poor energy investment. They are crippled by the thermodynamic energy losses of all the transformations involved from making a low-energy-density, solid carbohydrate into a

high-energy-density, liquid hydrocarbon. If they were used to provide the energy for their own manufacture, or even allowed to compete without subsidies, there would be little if anything profitable left at the end to market.[54]

Every fuel with an EROI less than the prevailing average drags down the average and multiplies rather than eases the burden placed on higher EROI fuels. The only way to displace imported petroleum use and thereby improve national security is to domestically produce fuels with higher EROI than refined petroleum. Any such fuel will be instantly adopted because the evidence of its higher EROI will be a lower price.[55] Without petroleum or a replacement source for massive quantities of hydrogen to make ammonia, all biomass yields, particularly food, will plummet toward what they were before Haber's monumental discovery in 1909, with devastating consequences for the world.[56] Accelerating the use of petroleum by using it to make biofuels accelerates future scarcity, undermines international food security, is counterproductive to "green" energy goals, and is not sound energy strategy.

The Real Cost of Biofuels

The Military's Cost

One of the core goals of the DoD's new *Operational Energy Strategy* is to reduce military energy costs so the department can "shift resources to other warfighting priorities, and save money for the American taxpayers."[57] The civilian leaders of the US Navy quote the statistic that a $1 rise in the cost of a barrel of oil increases annual fuel costs by $31 million.[58] Yet, the cheapest price the Navy has paid for any biofuel to date is $1,123.50 per barrel.[59] Since 2007, the military has spent $61.9 million on 1.28 million gallons of biofuel, averaging more than $48 a gallon, or $2,000 a barrel, and costing taxpayers $88 million more than if conventional fuel had been purchased (fig. 4).[60] This does not include more than $30 million paid for pure research on alternative fuels and recent additional millions for biorefineries obligated under the Defense Production Act in partnership with the Departments of Energy and Agriculture.[61]

DoD Biofuels Purchases						
Date	**Contract**	**Vendor**	**Fuel**	**Gallons**	**$ Total**	**Per Gallon**
31 Aug 2009	SP0600-09-D-0519	Sustainable Oils	Camelina JP-5	40,000	2,644,000	**$66.10**
31 Aug 2009	SP4701-09-C-0040	Solazyme	Algae F-76	20,055	8,574,022	**$427.53**
1 Sep 2009	SP0600-09-D-0518	Solazyme	Algae JP-5	1,500	223,500	**$149.00**
15 Sep 2009	SP0600-09-R-0704	UOP (Cargill)	Tallow JP-8	100,000	6,400,000	**$64.00**
15 Sep 2009	SP0600-09-D-0520	Sustainable Oils	Camelina JP-8	100,526	6,715,137	**$66.80**
29 Jun 2010	SP0600-09-D-0519	Sustainable Oils	Camelina JP-5	150,000	5,167,500	**$34.45**
26 Jul 2010	SP0600-10-D-0489	Sustainable Oils	Camelina JP-8	34,950	1,349,070	**$38.60**
4 Aug 2010	SP0600-10-D-0490	Sustainable Oils	Camelina JP-8	19,672	759,339	**$38.60**
31 Aug 2010	SP0600-09-D-0520	Sustainable Oils	Camelina JP-8	100,000	3,490,000	**$34.90**
31 Aug 2010	SP0600-09-D-0517	UOP (Cargill)	Tallow JP-8	100,000	3,240,000	**$32.40**
10 Sep 2010	SP4701-10-C-0008	Solazyme	Algae F-76	75,000	5,640,000	**$75.20**
26 Aug 2011	SP4701-10-C-0008	Solazyme	Algae F-76	75,000	4,600,000	**$61.33**
23 Sep 2011	SP0600-11-R-0703	Gevo	Alcohol to JP-8	11,000	649,000	**$59.00**
30 Sep 2011	SP0600-11-D-0530	UOP	Bio JP-8	4,500	148,500	**$33.00**
30 Nov 2011	SP0600-11-R-0705	Dynamic Fuels (Tyson+Syntroleum), Solazyme	Tallow & Algae JP-5 Tallow & Algae F-76	100,000 350,000	12,037,500	**$26.75**
23 Sep 2011	DTRT5711C10058 (DoT/FAA, not DoD)	UOP	Gevo Isobutano to Jet Fuel	100	1,124,899	**$11,248.99**
2 Feb 2012	N68936-12-P-0209	Albemarle	Cobalt n-Butanol to Jet Fuel	55	245,000	**$4,454.55**
DoD Synthetic Fuels Purchases						
6 Jun 2007	SP0600-07-D-0486	Equilon	Natural Gas to Aviation Kerosene	315,000	1,075,694	**$3.41**
26 Jun 2008	SP0600-08-D-0496	SASOL	Coal to Aviation Kerosene	60,000	225,000	**$3.75**
3 Jul 2008	SP0600-08-D-0497	SASOL	Coal to Aviation Kerosene	335,000	1,306,500	**$3.90**
30 Sep 2009	SP0600-09-D-0523	PM Group	Natural Gas to Diesel	20,000	140,000	**$7.00**
DoD Bulk Contract Conventional Fuel Purchase						
FY 2010	Various		JP-8 Jet Fuel JP-4 / Jet A-1 JP-5 Jet Fuel F-76 Fuel Oil Motor Gasoline	2,296M 1,249M 541.8M 805.7M 70.7M	5,201M 2,884M 1,175M 1,816M 174.1M	**$2.26** **$2.31** **$2.17** **$2.25** **$2.46**
FY 2011	Various		JP-8 Jet Fuel JP-4 / Jet A-1 JP-5 Jet Fuel F-76 Fuel Oil Motor Gasoline	2,079M 1,246M 529.3M 875.9M 59.0M	6,478M 4,032M 1,572M 2,590M 186.6M	**$3.12** **$3.24** **$2.97** **$2.96** **$3.16**

Figure 4. DoD comparative fuel purchases

The Nation's Cost

The per-gallon price paid by the military for biofuels is only a fraction of the US government's full cost. Government officials profess grave concern at the volatility of oil prices, and economic forecasters cite statistics that a $10 rise in the price of a barrel of oil slows the US economy 0.2 percent and kills 120,000 jobs.[62] Yet, the federal government is voluntarily paying more than $10 a barrel in biofuel subsidies (fig. 5).[63] The Department of Enegy (DoE) pumped $603 million into biofuel refinery construction in 2010 as part of $7.8 billion in annual biofuels spending.[64] Despite millennia of ethanol production as a beverage, 190 years of ethanol production as a fuel, and six years of huge subsidies and blending mandates and guaranteed markets since 2005, a joule of corn ethanol energy today is still more expensive than a joule of gasoline energy. The American Automobile Association reports as of December 2012 that the mpg-corrected price of E85 ethanol at the gas pump is 40 cents a gallon higher than premium gasoline.[65] Because of mandatory blending of lower energy density ethanol in gasoline, consumers in 2010 paid $8.1 billion at the gas pump for energy that was not put into their tanks. When added to the $6.1 billion in federal subsidies given out by the US Treasury and taxpayers as ethanol tax credits, the United States paid a $14.2 billion premium in 2010 to displace 6.4 percent of its gasoline energy with ethanol—and the cheaper gasoline that was displaced was exported. [67]

Energy Source	Federal Subsidies (millions of $)	Domestic Production (million bbl of oil equivalent)	Subsidy per barrel of energy produced
Coal	$1,358	3,793	$0.36
Oil and Gas	$2,820	6,229	$0.45
Hydro	$216	437	$0.49
Nuclear	$2,499	1,451	$1.72
Geothermal	$273	36	$7.63
Biomass/fuel	$7,761	747	$10.39
Wind	$4,986	159	$31.39
Solar	$1,134	22	$52.30
Total	**$21,047**	**13,921**	**Average = $1.63**

Figure 5. US federal government energy subsidies in 2010

The Nation's Gain

A true primary energy source, like a true food source, cannot be subsidized. It must, by definition, yield many times more energy (and wealth) than it consumes, or else it is an energy sink. Critics of petroleum often claim it is subsidized, but when both sides of the balance sheet are considered, the money is revealed to be flowing the other way. All federal subsidies and tax breaks for oil and natural gas in 2010, as officially tallied across all government agencies and reported to Congress, totaled $2.82 billion, equaling 45 cents per barrel produced domestically. Against that outlay, the federal government collected $56.1 billion in oil company corporate taxes and excise taxes on retail gasoline and diesel, equaling $9.01 per barrel—a 2,000 percent return.[68] State and local governments collected similar shares in taxes and fees as well. It is not by subsidies that fossil fuels have grown to produce 82 percent of US energy, but by the merits of EROI, energy density, and power density in competition with other energy alternatives. Oil and gas are true primary energy sources that nourish rather than starve the US government and economy. Global oil and gas energy is a $3.8 trillion industry that fully subsidizes the rentier economies of 10 petro states and partially subsidizes the economies of 70 more producers.[69] In the United States alone, there are 536,000 active crude oil wells, 504,000 active natural gas wells, dozens of continent-spanning pipelines, a colossal interstate highway system, 17 million barrels-per-day of refining capacity, 160,000 gas stations, and a $1.5 trillion fraction of the global oil and gas industry that have all been funded out of oil and gas EROI margins.

Power Density and Land Use

If EROI and price were not fatal enough, the questions of land use and ultimate capacity must also be answered. Land is a finite national resource with many competing uses. Biofuel production is a terribly inefficient use of land, and this can best be illustrated with *power density*, a key metric for comparing energy sources. The 70 gallons of biodiesel per acre of soy and 500 gallons of ethanol per acre of corn are amazing agricultural achievements, but are dismal in terms of power density, and work out to only 0.069 and 0.315 W/m^2 respectively. While corn is 4.5 times better than soy, it is a factor of three below wind (1.13 W/m^2), 19 times worse than photovoltaic (PV) solar (6.0 W/m^2), and 300 times worse

than the 90 W/m^2 delivered by the average US petroleum pumpjack well on a two-acre plot of land.[70] Thirty square meters of today's cheapest PV solar panels can capture the same amount of energy per year as is in the ethanol from 10,000 square meters (2.5 acres) of cultivated switchgrass.[71] This is, coincidentally, about the same amount of land the average American family would require as biofuels pasture for each of its cars. Alternatively, that land could sustainably grow crops to feed 20 vegans or the crops and livestock to feed 2.5 meat-eating humans.[72] To replace the 28 exajoules of energy the United States uses every year just for cars, trucks, and airplanes would require more than 700 million acres of corn. This is 37 percent of the total area of the continental United States, more than all 565 million acres of forest, and more than triple the current amount of annually harvested cropland. Soy biodiesel would require 3.2 billion acres—one billion more than all US territory including Alaska. Oil palm biodiesel yields are reported to be as high as 640 gal/acre (6,000 L/ha), which exactly double the power density of corn ethanol but still fall far short of wind and solar power. As hinted earlier, algae biodiesel has the highest potential power density of any biofuel, but the predicted best case achievable, as limited by physical laws and laboratory-perfect conditions, is 6.42 W/m2—equivalent to what is produced today from the solar farm at Nellis AFB.[73] Figure 6 contrasts the land area of oil field, solar farm, wind farm, and cornfield

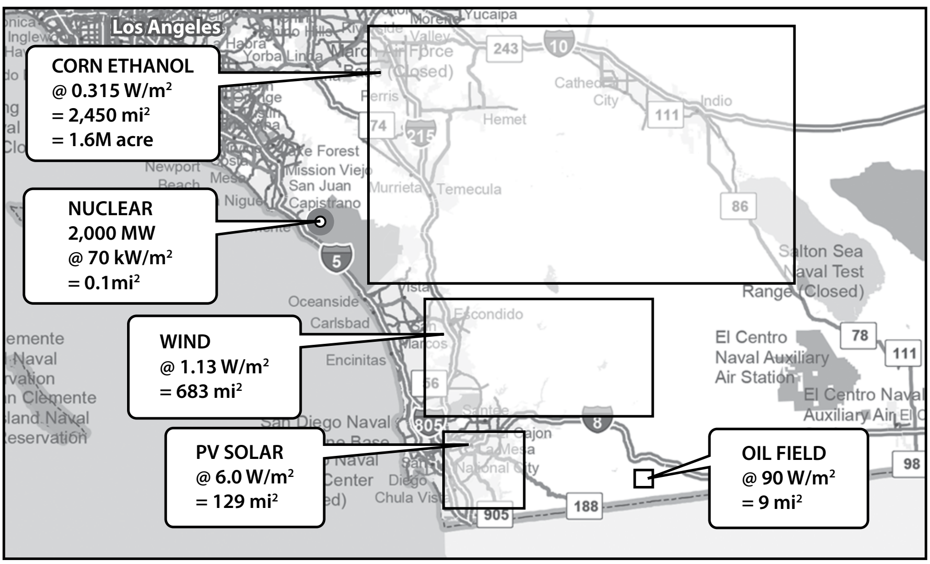


Figure 6. Power density "energy sprawl"

needed to replace the 2,000 MW of power produced by the San Onofre Nuclear Generating Station in Oceanside, California.

The high prices and environmental protections on land in developed countries make dedicating millions of acres to biofuels prohibitive, despite optimistic government studies that postulate turning most forests and arable land into agribusiness zones for biofuels.[74] Real-world economics compels energy farmers to look for cheaper cropland and water rights in less developed countries. The United States and European nations are primarily pursuing offshore land indirectly, such as through Blue Sugars' joint venture with Petrobras where Brazilian sugarcane bagasse feedstock was shipped to the United States for processing.[75] A 2010 World Bank analysis revealed that other wealthy countries, including Saudi Arabia, South Korea, and China, are pursuing a more direct strategy and have already purchased or leased more than 27 million acres of foreign land and water rights for remote cultivation of food, industrial, and biofuel crops. Chief locations for such land appropriation are Sudan, Mozambique, and Ethiopia, where millions are living hand-to-mouth on food from the UN World Food Program.[76] Even at today's small scale of production, biofuels' huge appetite for land already puts them in significant and direct competition with food production. Food must and will eventually win this competition because there is not enough suitable land for both. A recent European metastudy of 90 other studies concluded that only one-fifth of the world's energy demand could likely be met by biofuels without removing meat from the human diet or making massive land use changes beyond the 296 million acres which already must be put into cultivation to feed the population of 2050.[77]

The Competition of Fuel and Food

Around the world, cultivated food crops (corn, sugarcane, soy, palm, and various oilseeds) account for all statistically significant liquid biofuel production.[78] In 2008, world grain market prices tripled, mirroring the spike in global oil prices and proving the linkage between food calories and energy calories in the modern world. Grain prices to the poorest consumers increased as much as 50 percent, driving 8 percent more of Africa's population toward hunger and raising the world's undernourished population to approximately 850 million.[79] Today's market prices are still double what they were in 2007. Various studies of the 2008 food price spike have attributed as much as 70 percent of the increase

in corn and 100 percent of the increase in sugar prices to global diversion of food to biofuels.[80] A union of the world's preeminent food and financial assistance agencies, including the World Food Program and the Food and Agriculture Organization of the United Nations, has formally called for all G20 nations to drop their biofuels subsidies and mandates because of the impact on food prices around the world.[81] The fact is that every cultivated crop—food or nonfood—competes with every other cultivated crop for finite resources including water, land, agrichemicals, farm equipment, transportation, and financing. Putting more demand on these resources raises prices for everyone. Biofuels are becoming a huge threat to global food security, and thereby to global stability—a fact that should shape any military or political energy strategy. Many analysts now looking at the "Arab Spring" phenomenon recognize that, underlying the very real political aspirations of movements such as the revolution in Tunisia was outrage at skyrocketing food prices. What began as bread riots in Egypt due to the end of government grain subsidies became a hot-blooded revolt and coup.

As the global population sprints toward nine billion by 2050, there are 140,000 more mouths to feed every day. Food grain consumption is growing at 40 million tons per year.[82] Yet, because of enormous market-distorting subsidies, the United States today produces more corn for ethanol than for human food or cattle feed.[83] For decades past, it had surplus food crop capacity and used it to rescue other nations from famine. In 1965, Pres. Lyndon Johnson's administration shipped one-fifth of the US wheat crop to India during a devastating drought. With slack land now consumed by biofuels production, a drought such as the one that destroyed 40 percent of Russia's grain crop in 2010 would be devastating to national security—particularly because both food and fuel would be simultaneously affected. The negative consequences of biofuels on food crop production have been understood by the US government since a panel of scientists appointed by the newly formed DoE rejected gasohol for this and other sound reasons in 1980.[84] Twenty-five years later, politics trumped science with the imposition of US ethanol mixing mandates and corn ethanol subsidies. If our greater interest is truly global peace and security, US farmers should be out of the fuel business and instead increasing food production for the growing market of direct export contracts with famine-wary nations.

Biofuels versus the Environment

Despite claims of reduced GHG and pollution emissions for biofuels, the reverse is now becoming apparent. Biofuels have roughly the same tailpipe or flue gas emissions as conventional fuels, but until recently they automatically earned "green" and "reduced emissions" badges through simplistic accounting tricks that assumed all their carbon was recycled from the atmosphere and largely ignored the pollutants.[85] New, more thorough studies that consider the full fuel creation and combustion lifecycles (as in figs. 2 and 3 above) are now showing cultivated liquid biofuels to be more damaging to the environment and causing the release of more CO_2 and other greenhouse gases and pollutants per unit of energy delivered than fossil fuels.[86]

Even the overall environmental impact of adding ethanol to gasoline as an oxygenate has been shown to be negative—it does nothing to improve the emissions of US cars built since 1993, reduces the fuel economy of every gasoline vehicle, increases emissions of some smog precursors, and increases the environmental hazard of spills because of increased miscibility with water.[87] The most important change in the new studies is the proper accounting of land-use changes driven by biofuel cultivation, such as converting forests to cropland by burning. This widespread practice has been accelerated around the world by biofuels agriculture and is releasing centuries of carbon sequestered in forest biomass back into the atmosphere from these natural carbon sinks. Such burning strikes a double blow because it also destroys a dense living biome with a huge perpetual appetite for CO_2. Calculations indicate that large-scale conversion of virgin land to biofuel production has already released and continues to release so much CO_2 into the atmosphere that it may be centuries before this surge can be offset by the recycled carbon in the resulting biofuels, if at all. The continued burning of millions of acres of forest and peat lands to make room for oil palms has made Indonesia the world's third highest producer of CO_2, after the United States and China.[88]

The Water Problem

A final downside to biofuels is water demand. *Water footprint* is the term for how much fresh water is consumed or rendered unusable by a particular activity. This can happen by evaporation, by removal to inaccessible parts of the ecosystem, or by contamination with chemicals

such as industrial discharges or fertilizer runoff. Water use also represents a dimension of competition with food agriculture, but it is even more urgent and fundamental in its own right. While "peak oil" continues to be elusive (global petroleum production and proven reserves both set new record highs in 2011),[89] "peak water" has already arrived for much of the world. One third of all countries are today considered "water poor." Two of every five people do not have enough water for basic sanitation, and nearly one in five do not have enough to drink.[90] Many scientists and economists observe falling water tables and depleting aquifers due to overpumping (including the massive Central Valley and High Plains aquifers in the United States) and predict this will expand to a global water crisis before 2030.[91] Much of the Middle East and a growing number of other nations, including China, Japan, Australia, and Spain, are now dependent upon desalination of seawater for a significant fraction of their fresh water needs.[92] To put this dependence into perspective, consider that a US nuclear aircraft carrier can desalinate 400,000 gallons of water a day.[93] The current desalination demand of the world exceeds 78 million cubic meters per day with 11 percent annual growth.[94] This equates to 51,500 aircraft carriers worth of desalination capacity with 5,600 more being built each year. Saudi Arabia is currently willing to spend one liter of ethanol-equivalent energy in crude oil to desalinate 200–300 liters of water.[95] How do these economics mesh with biofuels?

Conventional gasoline has a water footprint of 2.3–4.4 liters of water per liter of ethanol-equivalent energy (L/L), including water injected into the ground for enhanced oil recovery and water used in refining.[96] In contrast, global averages for biofuels range from sugar beet ethanol (1,388 L/L) to corn ethanol (2,570 L/L) to soy biodiesel (13,676 L/L) to rapeseed biodiesel (14,201 L/L) to jatropha biodiesel (19,924 L/L).[97] Current state of the art for installed seawater desalination plants ranges from 126 to 970 liters of water per liter of ethanol-equivalent energy.[98] So, under absolute best case circumstances, sugar beet feedstock cannot produce enough ethanol fuel energy to desalinate enough water to grow a replacement crop, let alone provide leftover ethanol as fuel. Biofuels' huge dependence upon water means they are not truly a renewable fuel in any location where water is being depleted. *Not one biofuel crop is renewable in desalinated seawater*. Under the president's recently published update to Executive Order 13603 that specifies responsibilities under the Defense Production Act, the secretary of defense is now responsible

for the US water supply.[99] That should cause some reflection regarding the DoD's promotion of biofuels. When Saudi Arabia and a third of the world are willing to spend a liter of fuel for less than 1,000 liters of water, how long can others get away with spending 10,000 liters of water for one liter of biofuel?

Conclusions and Recommendations

Ultimately, biofuels are limited by the sun. If they rely exclusively on solar energy to make biomass without adding fossil fuel energy, the EROI can be high enough, but the power density will be far too low, even at maximum theoretical photosynthesis performance. If yield is boosted with fossil fuel hydrogen or carbon, fossil fuel use increases, biofuel EROI plummets and drags overall EROI with it, power density is still too low, and civilization ends up even more starved for power. One way out of this dilemma is to create a plentiful supply of hydrogen from a non–fossil fuel source. However the only prospect is to electrolyze hydrogen from water using nuclear power. If we had such a surplus of nuclear power electricity and hydrogen, we would use it directly for power, not for inefficient biomass conversion. This litany is the inescapable catch-22 of biofuels.

Converting natural gas hydrocarbons into ammonia fertilizer and then into the carbohydrates of plant biomass is a sequence of transformations that irreversibly consumes some usable energy in each step. That loss of energy can be justified if the crop being grown is food and is of greater need than the energy used to grow it. However, completing the circle by converting that plant's carbohydrate biomass back into hydrocarbons for fuel makes the whole process a futile analog of the perpetual motion machine. Improvements in technology can reduce the amount of energy lost in each conversion but cannot eliminate it. Any wood, grass, peat, bagasse, coal, natural gas, or oil will deliver much more benefit to civilization if used directly and efficiently as fuel by a consumer whose needs are compatible with its limitations, rather than by using its energy to make biofuels. As long as the preponderance of ammonia and free hydrogen and organic compounds used in agriculture are derived from petroleum and natural gas, cultivating biofuels will defy all logic. Biofuels can never be cheaper than nor replace fossil fuels while fossil fuels comprise the bulk of the energy invested to make them.

Imagine if the US military developed a weapon that could threaten millions around the world with hunger, accelerate global warming, incite widespread instability and revolution, provide our competitors and enemies with cheaper energy, and reduce America's economy to a permanent state of recession. What would be the sense and the morality of employing such a weapon? We are already building that weapon—it is our biofuels program. For the sake of our national energy strategy and global security, we must face the sober facts and reject biofuels while advocating an overall national energy strategy compatible with the laws of chemistry, physics, biology, and economics. This revised strategy must acknowledge several key aspects:

- Liquid hydrocarbons are unmatched as transportation fuel. Using hydrocarbons to process biomass into transportation fuel is detrimental to civilization's energy balance and must be avoided.
- Renewable fuels must be truly renewable in all their ingredients, and all biofuels under consideration today fail in one or more categories of water footprint, soil nutrient depletion, eutrophication, lifecycle GHG, air pollution, and overall energy balance.
- Not even today's best liquid biofuels have any prospect of simultaneously attaining the 6:1 threshold EROI necessary to support a healthy modern civilization while also achieving the massive yields per acre necessary to supplant any significant fraction of the national energy supply. Boosting yields using fossil fuel for ammonia fertilizer, pesticide and herbicide feedstock, farm equipment fuel, transportation fuel, processing plant energy, distillation energy, enzyme feedstock, or hydrotreatment hydrogen lowers EROI and undermines every clean and green energy objective.
- Government energy policies that restrict domestic development of a nation's highest EROI energy sources and fuels—such as hydropower, coal, natural gas, and petroleum—are tantamount to caps on thermodynamic efficiency, economic health, and international competitiveness. Conversely, the nations that pursue the highest EROI energy will have the greatest potential to grow their economies and have every prospect of advantage over countries limited to lower EROI sources. The US government should end subsidies and market-distorting policies that encourage low-EROI energy sources over high-EROI sources.

- Petroleum and natural gas are true primary energy sources and fuel modern agriculture. To conserve petroleum as a limited resource, it is best used directly as fuel. Use of fossil fuel energy to accelerate food crop growth may be justifiable, but its use to accelerate energy crop growth is ludicrous on its face, as the result is less overall efficiency of energy and greater net consumption of petroleum. Government policy should restrict the use of artificial ammonia-based fertilizers to food crops only.
- The price of oil, like that of any other global free-market commodity, is volatile and subject to war, politics, and speculation. However, biofuels are subject to both oil and agricultural market forces and are at the mercy of weather as well. Biofuel prices have proven as volatile as oil prices and are likely to be more so once subsidies end. In addition, it is logically indefensible to buy a $30.00 per gallon fuel over worries about the price volatility of a $3.00 per gallon fuel.
- The technologies most in need of Manhattan Project–level attention by our global security strategists and national scientific laboratories are water production and food agriculture to support the nine billion people of 2050. The government should cease funding biofuel refinery construction and instead offer incentives for enhanced food production and water desalination efficiencies.
- The best use of agricultural land and water is to produce sufficient food for the United States and a surplus for the rest of the world. This has been before and can once again be a major contribution to security and stability in the world.
- Biomass is an inefficient middleman between solar energy and fuel. A better approach is to bypass the creation of biomass completely and directly synthesize liquid fuel from sunlight. The US government should cease funding biofuel research and instead offer prizes for milestones in direct fuel photosynthesis, which is a much more worthy line of research.[100]
- The only sensible use of biomass as fuel is to harvest unfertilized biomass from unmanaged land and consume it as is (e.g., firewood), without wasteful attempts to transform it into liquid fuel.

- The best-case power density predicted for any biofuel is already attained by today's PV solar panels. The US government should cease subsidizing biofuels and instead reward improved PV solar panel performance.
- Mandating the use of higher-EROI fossil fuels to make lower-EROI biofuels requires the overall consumption of more energy to deliver the same usable power output. Current US biofuels policy is accelerating rather than decreasing the use of fossil fuels and also increasing lifecycle ecological damage and GHG emissions due to destructive global land-use change and harmful agrichemical side effects. This is the exact opposite of "clean and green." The government should set policies that favor and optimize the use of hydrocarbons for fuel and carbohydrates for food and not confuse or undermine the efficiency of either by conflating them.
- CO_2 is not the only GHG. Agriculture is the leading producer of nitrous oxide (N_2O) and a major producer of methane (CH_4), which together comprise more than 26 percent of current total atmospheric GHG effects.[101] The US government should apply any caps or levy any taxes equitably across all greenhouse gases in proportion to their global warming potentials. Any per-ton penalties imposed on CO_2 should be levied against CH_4 at 69 times the rate and against N_2O at 298 times the rate to reflect relative per-ton global warming potentials.[102]
- The US military and federal government need to rationally and legally define *renewable*, *sustainable*, and *green* and enforce empirical standards for meeting these criteria based upon rigorous lifecycle analyses. Section 526 of the Energy Independence and Security Act of 2007 specifies that the lifecycle GHG emissions of any alternative or synthetic fuel purchased by the US government must be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources.[103] In light of recent research, and in the interest of curbing global warming, the US government should reexamine all §526 certifications issued to date for biofuels and blends. Any that do not consider the full biofuel lifecycle comprising land-use change for fuel creation as well as combustion, or that neglect N_2O emissions, should be invalidated.
- Global air and long-haul transportation and agriculture are currently very dependent on fossil fuel energy. It is unlikely that physically superior combustion fuels or fertilizers will be found. If the world runs out of

fossil fuels without an alternative source for massive amounts of energetic hydrogen and carbon, civilization also immediately runs out of transportation fuel. To the extent that fossil fuels are judged to be running out, the government should ensure there is excess electrical capacity from non–fossil fuel power plants to electrolyze sufficient quantities of hydrogen from water for transportation fuel and agricultural purposes.

We must understand that a national energy strategy is nothing less than a national survival strategy. Those who would craft such strategy or advise policymakers need to be well-grounded in chemistry, thermodynamics, biology, and economics, so they might discern the difference between promising avenues of research and perpetual motion schemes that defy physical laws and waste our nation's time and treasure. What remains is for leaders and policymakers to catch up with the science and adjust their energy and security strategies to match the objective facts. An effective energy strategy for the United States must be informed by history and science and must exploit rather than defy the laws of nature to increase energy independence and global stability. SSQ

For an extended version of this article, visit http://www.au.af.mil/au/ssq/.

Notes

1. 10 USC §2924—"Definitions" contains definitions of *energy security*, *operational energy*, and *renewable energy sources*, among others, as specified in the National Defense Authorization Act of 2012, http://www.law.cornell.edu/uscode/text/10/2924?quicktabs_8=1#quicktabs-8.

2. "How Much Petroleum Does the United States Import and from Where?" *Energy Information Administration*, 16 July 2012, http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6.

3. See James T. Bartis and Lawrence Van Bibber, *Alternative Fuels for Military Applications* (Santa Monica, CA: RAND, 2011), http://www.rand.org/pubs/monographs/MG969.html; and Dina Fine Maron, "Biofuels of No Benefit to Military—RAND," *New York Times*, 25 January 2011.

4. See James T. Bartis, *Promoting International Energy Security* (Santa Monica: RAND, 2012), http://www.rand.org/pubs/technical_reports/TR1144z1.html; and National Research Council (NRC), *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy* (Washington: National Academies Press, 2011).

5. *Bioenergy—Chances and Limits* (Halle, GE: Nationale Akademie der Wissenschaften—Leopoldina, 2012), http://www.leopoldina.org/en/publications/detailview/?publication[publication]=433.

6. NRC Committee on the Sustainable Development of Algal Biofuels, *Sustainable Development of Algal Biofuels in the United States* (Washington: National Academies Press, 2012).

7. Organisms that have the hydrogenase uptake enzyme (HUP+), such as soil and legume root bacteria, can capture and oxidize H_2 into $2H^+ + 2e^-$ and directly harvest that energy. See Z. Dong and

D. B. Layzell, "H_2 Oxidation, O_2 Uptake and CO_2 Fixation in Hydrogen Treated Soils," *Plant and Soil* 229, no. 1 (2001): 1–12, http://www.springerlink.com/content/qp73k5770103075r/abstract/.

8. A liter of gasoline contains 116 grams of hydrogen compared to 71 grams per liter in pure liquid hydrogen.

9. Cultivated crops respond with dramatically increased yields to energy supplied by hydrogen as pure H_2 gas or as any form of the ammonia molecule including anhydrous ammonia (NH_3), the ammonium ion (NH_4^+), and urea ($(NH_2)_2CO$). In each of these molecules, the hydrogen atoms are also the energy carriers and greatly outnumber the nitrogen. Studies have shown that fertilizing with pure hydrogen gas (H_2) without adding nitrogen can greatly boost soil bacteria activity and biomass synthesis. See Dong and Layzell, "H_2 Oxidation, O_2 Uptake and CO_2 Fixation in Hydrogen Treated Soils"; and Dong et al., "Hydrogen Fertilization of Soils—Is This a Benefit of Legumes in Rotation?" *Plant, Cell and Environment* 26, no. 11 (November 2003): 1875–79. http://doi.wiley.com/10.1046/j.1365-3040.2003.01103.x. Applying ammonia fertilizer to crops that are robust nitrogen fixers such as soy still results in substantial gains. See Richard B. Ferguson et al., "Fertilizer Recommendations for Soybean," University of Nebraska Institute of Agriculture and Natural Resources, August 2006, http://www.ianrpubs.unl.edu/live/g859/build/g859.pdf. For details of how hydrogen gas and ammoniac compounds serve as fuel to plants and bacteria, see Susanne Stein et al., "Microbial Activity and Bacterial Composition of H_2-treated Soils with Net CO_2 Fixation," *Soil Biology and Biochemistry* 37, no. 10 (October 2005): 1938–45; D. C. Ducat et al., "Rewiring Hydrogenase-Dependent Redox Circuits in Cyanobacteria," *Proceedings of the National Academy of Sciences* 108, no. 10 (8 March 2011): 3941–46, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3053959/; and F. B. Simpson and R. H. Burris, "A Nitrogen Pressure of 50 Atmospheres Does Not Prevent Evolution of Hydrogen by Nitrogenase," *Science* 224, no. 4653 (8 June 1984): 1095–97, http://www.sciencemag.org/cgi/doi/10.1126/science.6585956. Once ammonia becomes available in the soil or plant roots, whether fixed by bacteria or humans, it reacts with water and oxygen and decomposes into hydrogen ions, hydrogen gas, and nitrate ions in a process known as "nitrification." These subcomponents serve as energy packages and building blocks supporting the myriad additional reactions and processes of biosynthesis. Partial oxidation of ammonia produces nitrous oxide (a GHG) and hydrogen gas: $2NH_3 + O_2 \rightarrow N_2O + H_2O + 2H_2$. Full decomposition of ammonia in water solution with oxygen produces hydrogen ions and nitrate ions and completes nitrification: $NH_3 + H_2O + 2O_2 \rightarrow 2H^+ + NO_3^- + OH^- + H_2O$.

10. Hydrogen-free sodium nitrate ($NaNO_3$) fertilizer comprised only 0.046 percent of commercial nitrogen fertilizer use in 2010. Virtually 100 percent of the 20 million tons of "nitrogen" fertilizer used annually in the United States is ammonia-based and made with hydrogen from natural gas. See "Fertilizer Use and Price," USDA Economic Research Service, 4 May 2012, http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx.

11. Symbiotic rhizobial root bacteria get sugar from the host plant and use some of that energy and hydrogen to create NH_3 and H_2 gas and release these to the plant and into the soil. Soil bacteria metabolize the soil ammonia and H_2 and use that energy to break down soil minerals and materials such as chitin and lignin in humus into reduced carbon and mineral nutrients usable by the plant. For various aspects of the energy relationship between plants, bacteria, and ammonia, see P. Mylona, K. Pawlowski, and T. Bisseling, "Symbiotic Nitrogen Fixation," *Plant Cell*, no. 7 (July 1995): 869–85, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC160880/; Rifat Hayat et al., "Soil Beneficial Bacteria and Their Role in Plant Growth Promotion: a Review," *Annals of Microbiology* 60, no. 4 (28 August 2010): 579–98, http://rd.springer.com/article/10.1007/s13213-010-0117-1; Guido Sanguinetti et al., "MMG: a Probabilistic Tool to Identify Submodules of Metabolic Pathways," *Bioinformatics* 24, no. 8 (21 February 2008): 1078–84, http://bioinformatics.oxfordjournals.org/cgi/doi/10.1093/bioinformatics/btn066; and V. N. Matiru, and F. D. Dakora, "Potential Use of

Rhizobial Bacteria as Promoters of Plant Growth for Increased Yield in Landraces of African Cereal Crops," *African Journal of Biotechnology* 3, no. 1 (2004): 1–7, http://www.ajol.info/index.php/ajb/article/view/14908.

12. Ernst Worrell et al., *Energy Use and Energy Intensity of the US Chemical Industry*, Lawrence Berkeley National Laboratory, April 2000.

13. A. M. Blackmer et al., "Nitrogen Fertilizer Recommendations for Corn in Iowa," Iowa Cooperative Extension Service, May 1997, http://www.extension.iastate.edu/Publications/PM1714.pdf.

14. Lance Gibson and Garren Benson, "Origin, History and Uses of Corn," Iowa State University Department of Agronomy, revised January 2002, http://www.agron.iastate.edu/courses/agron212/readings/corn_history.htm.

15. W. M. Stewart et al., "The Contribution of Commercial Fertilizer Nutrients to Food Production," *Agronomy Journal* 97, no. 1 (2005): 1, https://www.agronomy.org/publications/aj/abstracts/97/1/0001.

16. The widely accepted value for *biomass accumulation efficiency*, which is the fraction of total incident solar energy converted into biomass by photosynthesis, is 0.1 percent for most terrestrial plants. Plants use a much higher fraction of the sun's energy, but most of it goes into overhead costs such as evaporating water from the leaves to perform the work of drawing up nutrients from the ground against the force of gravity. Efficiencies as high as 4 percent under special circumstances have been reported, and it may be possible to boost this to 8 percent with human reengineering of the enzymes and mechanics. However, the highest efficiencies are achieved at very low light fluxes. Photosynthesis is saturated in capacity between 20 percent and 50 percent of maximum solar irradiance, and plants suffer radiation damage at these higher levels. Gains in net biomass accumulation remain elusive. See X. G. Zhu, S. P. Long, and D. R. Ort, "What Is the Maximum Efficiency with which Photosynthesis Can Convert Solar Energy into Biomass?" *Current Opinion in Biotechnology* 19, no. 2 (April 2008): 153–59, http://linkinghub.elsevier.com/retrieve/pii/S0958166908000165; Robert E. Blankenship et al., "Comparing Photosynthetic and Photovoltaic Efficiencies and Recognizing the Potential for Improvement," *Science* 332, no. 6031 (12 May 2011): 805–9; Harmut Michel, "The Nonsense of Biofuels," *Angewandte Chemie International Edition* 51, no. 11 (12 March 2012): 2516–18, http://doi.wiley.com/10.1002/anie.201200218; and Food and Agriculture Organization of the United Nations, *Renewable Biological Systems for Alternative Sustainable Energy Production*, chap. 1: "Biological Energy Production," September 2012, http://www.fao.org/docrep/w7241e/w7241e05.htm#1.2.1. For aquatic photosynthesis, see Kristina Weyer et al., "Theoretical Maximum Algal Oil Production," *Bioenergy Research* 3, no. 2 (8 October 2009): 204–13, http://www.springerlink.com/index/10.1007/s12155-009-9046-x.

17. The National Renewable Energy Laboratory (NREL) reports that solar radiation across the spectrum delivers energy to the cloudless southwestern US desert at a rate of 7.25 kWh/m^2-day = 302 W/m^2. At the observed biomass accumulation efficiency of 0.1 percent, this equates to 0.3 W/m^2 put into plant biomass, of which only a fraction can be eventually recovered as liquid fuel. See "Concentrating Solar Resource: Direct Normal," NREL, February 2009, http://www.nrel.gov/gis/images/map_csp_us_10km_annual_feb2009.jpg.

18. Solar photovoltaic (PV) AC power density of 6.0 W/m^2 is the current real-world, best-case, annualized value for large solar farm sites in southern US latitudes. This value is based on empirical analysis of nearly five years of actual performance of the Nellis AFB solar power plant (completed December 2007, $100 million cost, 72,416 panels on 140 acres, 14MW$_{pv}$ nameplate capacity, single-axis tracking array, 19 percent land coverage density, 24.5 percent capacity factor, producing 30 GWh/yr.). See "Nellis AFB Solar Power System," http://www.nellis.af.mil/shared/media/document/AFD-080117-043.pdf; and "Nellis Air Force Base," *Sunpower Performance Monitoring*, http://commercial.sunpowermonitor.com/Commercial/kiosk.aspx?id=1dd14d57-7840-4b2d-af0a-0fe0fdd5c872.

19. Other formulations of energy balance ratios include energy return on energy investment (EROEI), energy cost of energy (ECE), energy intensity ratio (EIR), and energy return on investment (ERI). EROI is the most commonly used in the literature, but there is some debate over what boundaries to apply to the formula. What is offered here is the simplest version of the concept.

20. S. A. L. M. Kooijman, *Dynamic Energy and Mass Budgets in Biological Systems* (Cambridge UK: Cambridge University Press, 2000).

21. This tipping point is also correlated with greater than 10 percent GDP expenditures on energy. See C. W. King, "Energy Intensity Ratios as Net Energy Measures of United States Energy Production and Expenditures," *Environmental Research Letters* 5, no. 4 (October 2010): 044006.

22. Charles A. S. Hall et al., "What is the Minimum EROI that a Sustainable Society Must Have?" *Energies* 2, no. 1 (January 2009): 25–47.

23. David J. Murphy and C. A. S. Hall, "Year in Review—EROI or Energy Return on (Energy) Invested," *Annals of the New York Academy of Sciences* 1185, no. 1 (January 2010): 102–18.

24. X-axis energy contributions are EIA data for 2010 reported in "Estimated U.S. Energy Use in 2010: ~98.0 Quads," Lawrence Livermore National Laboratory, 2011, https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2010/LLNLUSEnergy2010.png. Y-axis EROI values are depicted as ellipses to capture the range of values reported in different studies and for different sites. These values derived from the author's synthesis of published literature review including the following documents: DoE, "Fact Sheet: Energy Efficiency of Strategic Unconventional Resources," http://fossil.energy.gov/programs/reserves/npr/Energy_Efficiency_Fact_Sheet.pdf; "EROI Update: Preliminary Results Using Toe-to-Heel Air Injection," *Oil Drum*, http://www.theoildrum.com/node/5183/486247; Megan C. Guilford et al., "A New Long Term Assessment of Energy Return on Investment (EROI) for U.S. Oil and Gas Discovery and Production," *Sustainability* 3, no. 10 (October 2011): 1866–87, http://www.mdpi.com//2071-1050/3/10/1866/; Nate Hagens, "Proper Calculation of Brazilian Sugarcane EROI," *Oil Drum*, 24 March 2009; C. A. S. Hall, "Wave & Geothermal," *Oil Drum*, 14 May 2008; Hall, "Why EROI Matters," *Oil Drum*, 1 April 2008; Hall, "Provisional Results," *Oil Drum*, 8 April 2008; Hall, "Unconventional Oil: Tar Sands and Shale Oil," *Oil Drum*, 15 April 2008; Hall, "Nuclear Power," *Oil Drum*, 22 April 2008; Hall, "Solar, Wind and Hydro," *Oil Drum*, 29 April 2008; Hall et al., "What Is the Minimum EROI that a Sustainable Society Must Have?"; Hall et al. "Seeking to Understand the Reasons for Different Energy Return on Investment (EROI) Estimates for Biofuels," *Sustainability* 3, no. 12 (13 December 2011): 2413–32; Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (2006): 11206; King, "Energy Intensity Ratios as Net Energy Measures of United States Energy Production and Expenditures"; King and Hall, "Relating Financial and Energy Return on Investment," *Sustainability* 3, no. 10 (11 October 2011): 1810–32; David J. Murphy, "The Energy Return on Investment Threshold," *Oil Drum*, 25 November 2011; Murphy et al., "New Perspectives on the Energy Return on (Energy) Investment (EROI) of Corn Ethanol," *Environment, Development and Sustainability* 13, no. 1 (11 July 2010): 179–202; Murphy et al., "Order from Chaos: A Preliminary Protocol for Determining the EROI of Fuels," *Sustainability* 3, no. 10 (17 October 2011): 1888–1907; Tad W. Patzek, "A First-Law Thermodynamic Analysis of the Corn-Ethanol Cycle," *Natural Resources Research* 15, no. 4 (22 February 2007): 255–70; Bruce Pile, "The Alternative Energy No One Is Thinking About," *Seeking Alpha*; David Pimentel and Tad Patzek, "Ethanol Production: Energy and Economic Issues Related to U.S. and Brazilian Sugarcane," *Natural Resources Research* 16, no. 3 (21 August 2007): 235–42; and Hosein Shapouri et al., "Estimating the Net Energy Balance of Corn Ethanol," *Agricultural Economic Report* 721 (July 1995).

25. Corn ethanol EROI values in the literature range from 0.7–1.7:1 with a median value of 1.2:1. Many metastudies have compared and contrasted multiple EROI approaches and papers.

This author judges the most thorough and authoritative individual study to be Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." This study is one of several to promulgate a value of 1.25:1 and to find that any positive energy balance was entirely dependent upon giving energy credit for co-products. The most thorough and authoritative recent metastudy surveying multiple individual corn ethanol lifecycle analyses was judged to be Murphy et al., "New Perspectives on the Energy Return on (Energy) Investment (EROI) of Corn Ethanol." This study is actually less favorable and finds a neutral 1:1 EROI. Two USDA-funded studies have found values of 1.24:1 in 1995 and 1.34:1 in 2002. Shapouri et al., "Estimating the Net Energy Balance of Corn Ethanol"; and Shapouri et al., *The Energy Balance of Corn Ethanol: An Update* (Washington: USDA, July 2002).

26. The pure corn ethanol EROI can be estimated by dividing the petroleum-corn ethanol hybrid EROI of 1.25:1 by the pure petroleum EROI of 8:1 (discussed later under "opportunity cost") to yield 0.156:1 ~ 1:6.

27. Tad Patzek, "A Probabilistic Analysis of the Switchgrass Ethanol Cycle," *Sustainability* 2, no. 10 (30 September 2010): 3158–94, http://www.mdpi.com/2071-1050/2/10/3158/.

28. M. R. Schmer et al., "Net Energy of Cellulosic Ethanol from Switchgrass," *Proceedings of the National Academy of Sciences* 105, no. 2 (15 January 2008): 464–69.

29. National Academy of Sciences, *Renewable Fuel Standard*.

30. The cellulosic ethanol sector was recently rocked by the demise of Range Fuels, the signature creation of vocal biofuels proponent Vinod Khosla and recipient of the first USDA biofuels loan guarantee of $64 million in 2010. This failure eclipsed the 2009 fraud scandal and collapse of Cello, which was the Solyndra of cellulosic ethanol.

31. Randy Schnepf and Brent D. Yacobucci, *Renewable Fuel Standard (RFS): Overview and Issues* (Washington: Congressional Research Service [CRS], 14 October 2010), http://digital.library.unt.edu/ark:/67531/metadc31329/m1/1/high_res_d/R40155_2010Oct14.pdf.

32. See "2012 RFS2 Data," Environmental Protection Agency, 19 July 2012, http://www.epa.gov/otaq/fuels/rfsdata/2012emts.htm; "Producing Sustainable Fuel Ethanol Today," Blue Sugars Corporation, http://bluesugars.com/technology-production.htm; Meghan Sapp, "Petrobras, KL Energy Extend Cellulosic Ethanol Development Agreement," *Biofuels Digest*, 26 June 2012, http://www.biofuelsdigest.com/bdigest/2012/06/26/petrobras-kl-energy-extend-cellulosic-ethanol-development-agreement/; and *Federal Register* 77 no. 5 (9 January 2012), http://www.gpo.gov/fdsys/pkg/FR-2012-01-09/html/2011-33451.htm.

33. Matthew Wald, "Companies Face Fines for Not Using Unavailable Biofuel," *New York Times*, 9 January 2012.

34. For Gevo, see Kevin Bullis, "To Survive, Some Biofuels Companies Give Up on Biofuels," *MIT Technology Review*, 21 December 2011, http://www.technologyreview.com/energy/39371/. For Amyris, see Sophie Vorrath, "Biofuels: Have the Republicans Gutted Green Fuel?" *Renew Economy*, 17 May 2012, http://reneweconomy.com.au/2012/biofuels-have-the-republicans-gutted-green-fuel-62642. For Cellana, see Jim Lane, "Shell Exits Algae as It Commences a 'Year of Choices,'" *Renewable Energy World*, 31 January 2011, http://www.renewableenergyworld.com/rea/news/article/2011/01/shell-exits-algae-as-it-commences-year-of-choices.

35. Jim Lane, "The October Surprise: BP Cancels Plans for US Cellulosic Ethanol Plant," *Renewable Energy World*, 26 October 2012, http://www.renewableenergyworld.com/rea/news/article/2012/10/the-october-surprise-bp-cancels-plans-for-us-cellulosic-ethanol-plant. As of this writing, ZeaChem Inc., founded in 2002 and recipient of $297.5 million in grants and loan guarantees from the DoE and USDA, is operating its 250,000 gal/year biorefinery in Oregon as a demonstration facility, which means the product is not commercially competitive. Logen of Canada is still operating its 1,200 gal/day cellulosic ethanol facility in

demonstration mode with total historic production since 2004 averaging less than 200 gal/day. KiOR is starting up its new 10 million gal/year biorefinery in Mississippi that investors and the EPA have been promised will deliver commercial sales and profits from competitively priced gasoline and diesel made from wood. INEOS Bio is also in the process of commissioning an 8 million gal/year commercial cellulosic ethanol plant in Florida. Already expectations for these massive capital investments are being deflated with revised names such as "commercial demonstration" or "second generation demonstration" plant floating around and profitability target dates shifting years into the future. If these huge facilities remain "demonstration plants," it will mean that, once again, the promises have not been kept. Even if they somehow achieve marginal profitability under a regime of biofuel subsidies and mixing mandates and carbon taxes, they will still face an insurmountable capacity problem because of abysmal power density.

36. See Jim Lane, "Coskata Switches Focus from Biomass to Natural Gas; To Raise $100M in Natgas-Oriented Private Placement," *Biofuels Digest*, 20 July 2012, http://www.biofuelsdigest.com/bdigest/2012/07/20/coskata-switches-from-biomass-to-natural-gas-to-raise-100m-in-natgas-oriented-private-placement/; and Kevin Bullis, "Biofuels Companies Drop Biomass and Turn to Natural Gas," *MIT Technology Review*, 30 October 2012, http://www.technologyreview.com/news/506561/biofuels-companies-drop-biomass-and-turn-to-natural-gas/.

37. Alan Shaw, former CEO of Codexis, stated that "carbohydrates are not a substitute for oil. I was wrong in that, and I admit it. [They] will never replace oil because the economics don't work. You can't take carbohydrates and convert them into hydrocarbons economically. . . . It's a death blow that that maximum yield is about 30 percent." Quoted in Bullis, "Biofuels Companies Drop Biomass."

38. *Hydrotreatment* is most often used as a collective term for a set of processes necessary to refine or upgrade biofuels into true hydrocarbons that are "drop-in" compatible substitutes for conventional hydrocarbon applications. These steps include hydrogenation, deoxygenation, cracking, isomeration, fractionation, and using additives as necessary to adjust energy density, cetane, octane, volatility, cold flow properties, and lubricity. See Carlo Munoz, Jon Van Gerpen, and Brian He, *Production of Renewable Diesel Fuel*, National Institute for Advanced Transportation Technology, University of Idaho, June 2012, http://ntl.bts.gov/lib/46000/46200/46277/KLK766_N12-08.pdf.

39. Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels."

40. An EROI of 1:1 (300 GJ input vs. 317 GJ output) was reported if sun-dried product algal biomass was burned whole in a furnace extracting a thermodynamically perfect 100 percent of the HHV with no attempt to convert to a liquid fuel. See Andres F. Clarens et al., "Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks," *Environmental Science & Technology* 44, no. 5 (March 2010): 1813–19. A study that considered the costly biomass-to-liquid fuel conversion step found that the input energy required just to circulate the water in the cultivation ponds/tanks exceeded the biodiesel fuel energy output by a factor of seven. See Cynthia F. Murphy and David T. Allen, "Energy-Water Nexus for Mass Cultivation of Algae," *Environmental Science & Technology* 45, no. 13 (July 2011): 5861–68.

41. NRC, *Sustainable Development of Algal Biofuels in the United States*.

42. Photosynthetic stoichiometry for typical microalgae: $99.5\ CO_2 + 75.5\ H_2O + 7.5\ CO(NH_2)_2 + ½\ P_2O_5$ (+ sunlight) –>$[C_{107}\ H_{181}\ O_{45}\ N_{15}\ P] + 119.75\ O_2$ [carbon dioxide + water + urea + phosphate (+ sunlight) –> microalgae + oxygen]. In this case, one-sixth of the hydrogen (30 of 181 atoms) in the microalgae is from urea, not water. Most algae are grown heterotrophically with some hydrogen and carbon energy being provided in ammoniacal or saccharine form. Autotrophic algae growth requires only CO_2, water, phosphate, micronutrients, and sunlight but delivers

diminished yields. See E. D. Frank et al., *Life-Cycle Analysis of Algal Lipid Fuels with the GREET Model* (Oak Ridge, TN: DoE, August 2011), http://greet.es.anl.gov/publication-algal_lipid_fuels.

43. Robert Rapier, "Visit and Conversation with Executives at Solazyme," *Consumer Energy Report*, 23 October 2011, http://www.consumerenergyreport.com/2011/10/23/visit-and-conversation-with-executives-at-solazyme/.

44. Frank et al., *Life-Cycle Analysis*. Total energy to produce one functional unit of algae biodiesel of 2,589,441 BTU vs. 219,183 BTU to make one functional unit of conventional low-sulfur diesel = 11.8:1 ratio. Well-to-pump fossil fuel energy costs of 548,329 BTU vs. 215,388 BTU yield a ratio of 2.6:1.

45. Murphy et al., "New Perspectives on the Energy Return on (Energy) Investment (EROI) of Corn Ethanol."

46. The 8:1 petroleum fuel EROI is chosen as a conservative value from historical fluctuations within the range of 8:1 to 24:1 since 1920, per Guilford et al., "New Long Term Assessment."

47. The term *barrel of energy* is used here to represent a generic unit of energy for relative comparison purposes. The term is more specifically defined as the energy in a barrel of crude oil and has a value of 6.1306 GJ = 1.7029 MWh = 5.8106 MBTU. A barrel of crude oil has virtually the same energy content as a barrel of diesel fuel.

48. The fraction of crude oil that yields fuels vice feedstocks is based on "What a Barrel of Crude Oil Makes," *Texas Oil & Gas Association*, http://www.txoga.org/articles/308/1/WHAT-A-BARREL-OF-CRUDE-OIL-MAKES. CO_2 from fuel creation: 1 bbl x 42 gal/bbl of diesel @ 23.66 lb CO_2/gal for diesel combustion = 944 lb. The CO_2 from fuel combustion (all products): 11 bbl of crude x 42 gal/bbl x 22.99 lb CO_2/gal for crude combustion = 10,621 lb. Total CO_2: 944 lb + 10,621 lb = 11,565 lb (counting all carbon on the page = worst case). Input H_2O = 9 bbl x 42 gal/bbl x 6.6 gal/gal = 2,495 gal. The water footprint of petroleum covers all extraction and refining processes including water injection into older oil fields for secondary recovery. Maximum value of 6.6 gallons water per gallon of gasoline is used to make the calculation as conservative as possible and is based on May Wu and Yiwen Chiu, *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline—2011 Update* (2008; Oak Ridge, TN: DoE, July 2011).

49. Ksenia Galouchko, "Ethanol Follows Gasoline Higher after Iran Blocks Base Access," *Bloomberg*, 22 February 2012, http://www.bloomberg.com/news/2012-02-22/ethanol-follows-gasoline-higher-after-iran-blocks-base-access.html.

50. Fig. 3 depicts the same net energy output as fig. 2 (i.e., 8 bbl diesel equivalent). Each barrel of diesel equivalent energy input yields energy parity in 1.625 bbl of ethanol plus a 0.25 bbl diesel equivalent net energy profit in co-product DDGS. Ethanol has 0.615 times the volumetric energy density of diesel; therefore, it takes 52 bbl of ethanol to equal the energy in 32 bbl of diesel. Values of 478 gal/acre ethanol yield and 5 lb/gal of ethanol in DDGS yield are per 2008 survey of 90 dry-mill ethanol refineries as reported in Steffen Mueller, "News from Corn Ethanol: Energy Use, Co-Products, and Land Use," presentation at Near-Term Opportunities for Bio-refineries Symposium, Champaign, IL, 11–12 October 2010, http://bioenergy.illinois.edu/news/biorefinery/pp_mueller.pdf. Acreage of cornfield required : 52 bbl x 42 gal/bbl = 2,184 gal ÷ 478 gal/acre = 4.57 acre. DDGS co-product: 5 lb/gal x 2,184 gal = 10,920 lb CO_2 from fuel creation: 32 bbl x 42 gal/bbl x 23.66 lb CO_2/gal diesel = 31,799 lb. No CO_2 is charged for ethanol or DDGS consumption. Conservative calculation of CO_2-equivalent N_2O emissions (CO_2e) from corn fertilization: 2 percent of 150 lb/acre NH_3 x 4.6 acre = 13.8 lb NH_3 x 82.35 percent N mass fraction of NH_3 = 11.36 lb N ÷ 63.64 percent N mass fraction of N_2O = 17.86 lb N_2O x 298 multiplier for CO_2 warming potential equivalence = 5,321 lb CO_2e. Total CO_2e emissions: 31,799 lb CO_2 + 5,321 lb CO_2e = 37,120 lb CO_2e. H_2O for ethanol: 52 bbl x 42 gal/bbl x 1,220 gal/gal = 2.66M gal. (US average corn ethanol water footprint is 1,220 gal/gal, per Winnie Gerbens-Leenes et al., "The Water Footprint of Bioenergy,"

Proceedings of the National Academy of Sciences 106, no. 25 [3 June 2009]: 10219–23, http://www.pnas.org/cgi/doi/10.1073/pnas.0812619106). H_2O for diesel: 32 bbl x 42 gal/bbl x 6.6 gal /gal = 8,870 gal. Total H_20 = 2.66M + .009M = 2.67M gal (gasoline water footprint is 6.6 gal /gal, per Wu and Yiwen, *Consumptive Water Use*).

51. Hall et al., "Seeking to Understand the Reasons for Different Energy Return on Investment (EROI) Estimates for Biofuels."

52. *Annual Energy Review 2011* (Washington: Energy Information Agency, September 2012), http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.

53. E. C. Sherrard and F. W. Kressman, "Review of Processes in the United States Prior to World War II," *Industrial & Engineering Chemistry* 37, no. 1 (January 1945): 5–8, http://pubs.acs.org/toc/iechad/37/1.

54. The threshold test for any candidate for primary energy source or fuel is demonstrating the ability to bootstrap itself up in scale and energy productivity without outside assistance with an EROI greater than 6:1. To be commercially competitive it must match or exceed the current national average (approximately 12:1 for the United States). A true twenty-first-century fuel must deliver enough energy profit to build up its own production and distribution infrastructure just as coal and oil did in the previous two centuries. Such a test quickly reveals that the quality of energy measured in such things as EROI, energy density, power density, and *dispatchability* (controllability of energy delivery location, time, and rate) matter just as much as total power output. Until this level of performance is achieved, the energy candidate is a research and development experiment that cannot survive without subsidy. Conversely, any energy candidate that is receiving a net subsidy is by definition not an energy source.

55. For the firmly established correlation between EROI and price, see C. W. King and C. A. S. Hall, "Relating Financial and Energy Return on Investment," *Sustainability* 3, no. 10 (October 2011): 1810–32; and Murphy et al., "New Perspectives on the Energy Return on (Energy) Investment (EROI) of Corn Ethanol."

56. An alternative source of hydrogen is electrolysis from water. This could only be done with massive new sources of electrical power. If such power were available, we would use the resulting hydrogen directly as fuel and not bother with the less-efficient process of growing biomass for conversion into biofuels.

57. *Energy for the Warfighter: Operational Energy Strategy* (Washington: DoD, May 2011), http://energy.defense.gov/Operational_Energy_Strategy.pdf.

58. David Miller, "Biofuels Conference: Secretary of the Navy Says Military Can Lead the Way in Alternative Energy," *Dispatch* (Starkville, MS), 7 October 2011, http://www.cdispatch.com/news/article.asp?aid=13418.

59. $26.75 per gallon for Dynamic Fuels biofuel x 42 gal/bbl = $1,123.50 per barrel. Highest price paid was $4,454.55 per gallon = $187,089.00 per barrel. See fig. 5 for details.

60. Contract quantity and price data are from official government websites in 2012 and tabulated by contract number in fig. 4. Sources include General Services Administration's "Federal Procurement Data System—Next Generation" search page, https://www.fpds.gov/fpdsng_cms/; *FedBizOpps* search page, https://www.fbo.gov/; "Bulk Petroleum Contract Awards," Defense Logistics Agency: Energy, http://www.energy.dla.mil/bulk_petroleum/Pages/Contract_Awards.aspx; and Defense Logistics Agency: Energy, *Fact Book: Fiscal Year 2011*, http://www.energy.dla.mil/energy_enterprise/Documents/Fact percent20Book percent20FY2011 percent20Rev.pdf.

61. Ray Mabus, Steven Chu, and Thomas J. Vilsack, "Memorandum of Understanding between the Department of the Navy and the Department of Energy and the Department of Agriculture," June 2011, http://www.rurdev.usda.gov/SupportDocuments/DPASignedMOUEnergyNavyUSDA.pdf.

62. Neelesh Nerurkar, *US Oil Imports: Context and Considerations* (Washington: CRS, April 2011).

63. See "Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010," Energy Information Agency, July 2011, http://www.eia.gov/analysis/requests/subsidy/; and *Annual Energy Review 2011*. Subsidy amounts in table ES2 from the first reference are divided by 2010 data for US energy production for the respective forms of energy in the second reference.

64. DoE, "Energy.gov/List of Awardees," December 2011, http://energy.gov/sites/prod/files/recoveryactfunding.xls.

65. "AAA's Daily Fuel Gauge Report," American Automobile Association, 19 July 2012, http://fuelgaugereport.opisnet.com/index.asp.

66. A gallon of ethanol contains only two-thirds the energy of a gallon of gasoline; if priced at energy parity, it would be two-thirds the price. The 2010 average retail gasoline price (minus 18.4 cent/gal federal excise tax) = $2.58/gal x 2/3 = $1.72/gal (what ethanol should have cost). The 2010 average retail E85 price = $2.40/gal (what retail ethanol did cost to a close approximation). How much consumers overpaid at pump = $2.40/gal – $1.72/gal = $0.68/gal x 12 billion gallons blended in 2010 = $8.1 billion. For prices and tax credits see table 17-1 and footnotes in Office of Management and Budget, *Budget of the U.S. Government: Analytical Perspective Fiscal Year 2012* (Washington: OMB, 2011); and table A12 of "Annual Energy Outlook 2012," Energy Information Agency, June 2012, http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf.

67. Steve Hargreaves, "Gasoline: The New Big U.S. Export," *CNN Money*, 5 December 2011, http://money.cnn.com/2011/12/05/news/economy/gasoline_export/index.htm.

68. The 2009 tax data is presented by the EIA as it were the most recent available. That was a particularly bad year for IRS revenue from oil company taxes because of the economic crash; 2010 data is likely much higher. Oil companies paid $13.7 billion in corporate taxes, and consumers paid $42.4 billion in excise taxes, for a total of $56.1 billion in federal government revenues, per "EIA Financial Reporting System Survey, Form EIA-28 Schedule 5112, Analysis of Income Taxes," *Energy Information Agency*, 2009, ftp://ftp.eia.doe.gov/pub/energy.overview/frs/s5112.xls. Dividing $56.1 billion by the 6.23 billion barrels of oil and gas produced domestically in 2010 yields $9.01 per barrel. Federal excise taxes paid by consumers at the pump were 18.4 cents per gallon for gasoline and 24.4 cents per gallon for diesel.

69. "Market Cap Stock Rankings for Major Integrated Oil & Gas Industry," *YCharts*, 7 January 2013, http://ycharts.com/rankings/industries/Major%20Integrated%20Oil%20&%20Gas/market_cap.

70. See note 18 for solar power density derivation. Wind power density of 1.13 W/m^2 based on recent NREL data reporting 2.9 W/m^2 peak and 39 percent capacity factor as averaged across 2000–2009 US installations with nameplate capacity >20MW. See Paul Denholm et al., *Land-Use Requirements of Modern Wind Power Plants in the United States*, NREL, August 2009, www.nrel.gov/docs/fy09osti/45834.pdf. Corn ethanol power density of 0.315 W/m^2 based on 500 gal/acre-year, @ 76,321 BTU/gal LHV. Soy biodiesel power density of 0.069 W/m^2 based on 70 gal/acre-year @ 119,545 BTU/gal LHV. Average US crude oil well in 2011 produced 10.6 bbl/day @ 129,667 BTU/gal on a two-acre parcel of land, which equates to ~90 W/m^2. See *Annual Energy Review 2011*.

71. Patzek, "Probabilistic Analysis of the Switchgrass Ethanol Cycle."

72. John Jeavons, *How to Grow More Vegetables: And Fruits, Nuts, Berries, Grains and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine*, 6th ed. (Berkeley, CA: Ten Speed Press, 2004).

73. DoE NREL research has calculated the best case for algae yields from pure solar energy without fossil fuel or sugar energy augmentation to be 6,500 gal/acre-yr biodiesel = 17.8 gal/acre-day

= 6.42 W/m[2] LHV. Sapphire Energy projects it will achieve 14 gal/acre-day of algae biodiesel from 300 acres by 2014. See "In Race to Algae Fuel, Sapphire Scores Point for Open Ponds," *Sapphire Energy*, 6 September 2012, http://www.sapphireenergy.com/news-article/1135734-in-race-to-algae-fuel-sapphire. Algenol, using cyanobacteria animal algae instead of microphyte plant algae, and producing ethanol instead of lipids, recently announced it achieved 21.9 gal/acre-day of ethanol. This is equivalent to 5.6 W/m[2] and still below today's PV solar. See Paul Woods, "About Algenol," Algenol Biofuels, 27 September 2012, http://www.algenolbiofuels.com/.

74. See Robert Perlack et al., *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge, TN: DoE, 2005), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA436753; and Perlack and B. J. Stokes (leads), *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry* (Oak Ridge: DoE, 2011), http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf.

75. Blue Sugars Corporation, http://bluesugars.com/index.htm.

76. Klaus Deininger et al., *Rising Global Interest in Farmland* (Washington: World Bank, 2011).

77. Raphael Slade et al., *Energy from Biomass: The Size of the Global Resource* (London: UK Energy Research Centre, 2011).

78. Govinda Timilsina et al., *The Impacts of Biofuel Targets on Land-Use Change and Food Supply*, Iowa State University working paper, December 2010, http://www.econ.iastate.edu/sites/default/files/publications/papers/p12206-2010-12-15.pdf.

79. *The State of Food Insecurity in the World* (Rome: Food and Agriculture Organization of the United Nations, 2011), http://www.fao.org/docrep/014/i2330e/i2330e.pdf.

80. Timilsina et al., *Biofuels*.

81. *Price Volatility in Food and Agricultural Markets: Policy Responses* (Paris: Organisation for Economic Co-operation and Development, 2011).

82. Lester R. Brown, "The New Geopolitics of Food," *Foreign Policy*, May 2011, http://www.foreignpolicy.com/articles/2011/04/25/the_new_geopolitics_of_food.

83. Melissa C. Lott, "The U.S. Now Uses More Corn for Fuel than for Feed," *Scientific American*, 7 October 2011, http://blogs.scientificamerican.com/plugged-in/2011/10/07/the-u-s-now-uses-more-corn-for-fuel-than-for-feed/.

84. David Pimentel et al., "Report of the Gasohol Study Group," Energy Research Advisory Board, 29 April 1980.

85. Simon Eggleston et al., eds., *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, 5 vols. (Hayama, Japan: Institute for Global Environmental Strategies, 2006); and Timothy Searchinger et al., "Fixing a Critical Climate Accounting Error," *Science* 326, no. 5952 (23 October 2009): 527–28. http://www.sciencemag.org/content/326/5952/527.

86. For examples of recent studies finding that biofuels increase GHG and environmentally damaging emissions, see William K. Jaeger and Thorsten M. Egelkraut, "Biofuel Economics in a Setting of Multiple Objectives and Unintended Consequences," *Renewable and Sustainable Energy Reviews* 15, no. 9 (December 2011): 4320–33, http://www.deepdyve.com/lp/elsevier/biofuel-economics-in-a-setting-of-multiple-objectives-and-unintended-8FJ7IumYTW; Yi Yang et al., "Replacing Gasoline with Corn Ethanol Results in Significant Environmental Problem-Shifting," *Environmental Science & Technology* 46, no. 7 (5 March 2012): 3671–78, http://pubs.acs.org/doi/abs/10.1021/es203641p; Keith Smith and Timothy Searchinger, "Crop-based Biofuels and Associated Environmental Concerns," *GCB Bioenergy*, 7 June 2012; Thomas Walker et al., *Biomass Sustainability and Carbon Policy Study* (Brunswick, ME: Manomet Center for Conservation Sciences, June 2010), http://www.manomet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf; Jörn Scharlemann and William Laurance, "How Green Are Biofuels?" *Science* 319, no. 5859 (4 January 2008): 43–44; DoE, "Ethanol Benefits and Con-

siderations," *Alternative Fuels Data Center*, 28 January 2011, http://www.afdc.energy.gov/fuels/ethanol_benefits.html; and Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels."

87. For the negative air quality effects of ethanol as a gasoline additive, see article and supporting references within Pamela Franklin et al., "Clearing the Air: Using Scientific Information to Regulate Reformulated Fuels," *Environmental Science & Technology* 34, no. 18 (4 August 2000): 3857–63, http://dx.doi.org/10.1021/es0010103. For the increased environmental hazard of ethanol-blended fuel spills, see American Institute of Physics, "Mixing Processes Could Increase the Impact of Biofuel Spills on Aquatic Environments," *Phys.Org*, 16 November 2012, http://phys.org/news/2012-11-impact-biofuel-aquatic-environments.html.

88. Jonathan Lewis, *Leaping before They Looked: Lessons from Europe's Experience with the 2003 Biofuels Directive* (Boston: Clean Air Task Force, October 2007).

89. New record highs of 1.65 trillion barrels of proved reserves (1.9 percent annual increase) and 83.56 million bbl/day of production (1.3 percent annual increase) were set in 2011. Reserves have been growing faster than consumption since 1980. See *BP Statistical Review of World Energy June 2012*, British Petroleum, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2012.pdf.

90. Thomas Homer-Dixon, *The Upside of Down: Catastrophe, Creativity and the Renewal of Civilization* (London: Island Press, 2006).

91. Tom Gleeson et al., "Water Balance of Global Aquifers Revealed by Groundwater Footprint," *Nature* 488, no. 7410 (9 August 2012): 197–200, http://www.engr.scu.edu/~emaurer/classes/ceng139_groundwater/handouts/gleeson_groundwater_footprint_nature_2012.pdf.

92. See Lisa Henthorne, "The Current State of Desalination," November 2009; and "Water and Oil and Gas," *Desalination* 48, no. 39 (8 October 2012), http://www.desalination.com/wdr/48/39/and-oil-and-gas.

93. Tim Padgett, "The Postquake Water Crisis: Getting Seawater to the Haitians," *Time*, 18 January 2010, http://www.time.com/time/specials/packages/article/0,28804,1953379_1953494_1954584,00.html.

94. "Desalination Industry Enjoys Growth Spurt as Water Scarcity Starts to Bite," *AMEinfo*, 30 September 2012, http://www.ameinfo.com/desalination-industry-enjoys-growth-spurt-water-313351.

95. Al Shoaiba and two-thirds of Saudi desalination plants are multistage flash distillation technology, which require about 186 MJ energy input per cubic meter of water output. See Neil M. Wade, "Distillation Plant Development and Cost Update," *Desalination* 136, no. 1–3 (1 May 2001): 3–12, http://www.desline.com/articoli/4051.pdf.

96. Wu and Chiu, *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline*. Values adjusted by a two-thirds multiplier to correct for the lower energy density of ethanol vs. gasoline.

97. Gerbens-Leenes et al., "Water Footprint of Bioenergy."

98. Wade, "Distillation Plant Development and Cost Update."

99. Barrack Obama, *Executive Order 13603—National Defense Resources Preparedness*, 16 March 2012, http://www.whitehouse.gov/the-press-office/2012/03/16/executive-order-national-defense-resources-preparedness.

100. For two examples of ongoing research to photosynthesize fuel by directly recycling CO_2 and H_2O without making biomass, see Bill Scanlon, "Sun Shines on Old Idea to Make Hydrogen," *Renewable Energy World*, 5 November 2012; and "Sunshine to Petrol," Sandia National Labs, 9 November 2012, http://energy.sandia.gov/?page_id=776.

101. T. J. Blasing, "Recent Greenhouse Gas Concentrations," Carbon Dioxide Information Analysis Center, February 2012, http://cdiac.ornl.gov/pns/current_ghg.html.

102. N_2O and CO_2 have the same molecular mass of 44 Dalton, and their per-ton global warming contributions are in the direct ratio of the global warming potentials of their molecules (i.e., 298:1). CH_4 has a molecular mass of 16 Dalton and thus there are 44/16 more molecules per ton, each with a 25:1 increase in global warming potential, for a total increase in per-ton global warming potential of 69:1.

103. Energy Independence and Security Act of 2007, §526:

> No Federal agency shall enter into a contract for procurement of an alternative or synthetic fuel, including a fuel produced from nonconventional petroleum sources, for any mobility related use, other than for research or testing, unless the contract specifies that the lifecycle greenhouse gas emissions associated with the production and combustion of the fuel supplied under the contract must, on an ongoing basis, be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources. . . .
>
> No later than Oct. 1, 2015, and for each year thereafter, each Federal agency shall achieve ≥ 20 percent reduction in annual petroleum consumption and a 10 percent increase in annual alternative fuel consumption, relative to FY2005 baseline.